80113-0375 (BCS03208)

TITLE

A System and a Method for Reducing Tilt Effects in a Radio Frequency Attenuator

FIELD

[0001] The present system and method relate to signal attenuation. More particularly, the present system and method provide for reducing the difference in signal amplitude that occurs in an attenuator over various frequency ranges.

BACKGROUND

[0002] Radio receivers accept and process radio frequency (RF) transmitted energy signals to yield, generally, audible or visual information. Typically, the originally received RF signal will be converted to an intermediate frequency (IF) signal prior to reducing the desired signal information yet further to audio levels. Various signal processing functions may occur at the IF level, including signal attenuation as may be necessary to prevent the signal from exceeding a threshold level. Additionally, attenuation may be performed on a received signal to cancel a number of distortion products gained during transmission.

[0003] Figure 1 illustrates a constant impedance attenuator circuit (100) according to the prior art. Traditional constant impedance attenuator circuits are usually based on a classic PI or T circuit. The PI circuit illustrated in Figure 1 may be selected as it can have better high frequency, wide bandwidth behavior when compared to a T circuit. As shown in Figure 1, a constant impedance attenuator (100) may include a signal input (110) and a signal output (120). Additionally, a series resistive element (130) and a pair of shunt resistive elements (140, 150) may be coupled to the circuit as illustrated in Figure 1. For an attenuator with equal input and output impedances, the shunt elements (140, 150) have equal values. The absolute impedance values and the ratio of the shunt and series values determine the impedance and the attenuation value imposed onto received RF signals.

[0004] While the constant impedance fixed attenuator circuit (100) illustrated in Figure 1 is effective for input signals having a constant level, this is often not the case with a received signal. Rather, received signals and their uses often require variable attenuation levels and tight tilt specifications.

SUMMARY

[0005] A system for reducing tilt effects in a radio frequency (RF) attenuator includes an RF attenuator having at least one series diode, and at least one shunt branch including at least one shunt diode, the shunt branch being electrically coupled to the series diode, and a parallel resonant circuit electrically coupled to each of the at least one shunt branch, wherein the parallel resonant circuit is configured to compensate for a parasitic reactance in the RF attenuator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The accompanying drawings illustrate various embodiments of the present system and method and are a part of the specification. Together with the following description, the drawings demonstrate and explain the principles of the present method and system. The illustrated embodiments are examples of the present system and method and do not limit the scope thereof.

[0007] **Fig. 1** is a simple circuit diagram illustrating a prior art fixed attenuation, constant impedance attenuator circuit according to one exemplary embodiment.

[0008] **Fig. 2** is a simple circuit diagram illustrating a variable attenuation, constant impedance attenuator circuit including PIN diodes according to one exemplary embodiment.

[0009] **Fig. 3** is a circuit diagram illustrating a 6-diode PIN attenuator including tilt correction according to one exemplary embodiment.

[0010] **Fig. 4** is a simple block diagram illustrating an exemplary use of a 6-diode PIN attenuator including tilt correction according to one exemplary embodiment.

[0011] Throughout the drawings, identical reference numbers designate similar but not necessarily identical elements.

DETAILED DESCRIPTION

[0012] The present specification describes a method and a system for providing tilt correction in a 6-diode PIN attenuator. More specifically, a parallel resonant circuit including an inductor, a capacitor, and a resistor coupled in parallel are added to each of the

shunt legs of the 6-diode PIN attenuator. The added circuits exhibit high impedance at high signal frequencies and progressively lower impedance as frequency decreases, thereby canceling the effect of unwanted parasitic reactances that may exist in the 6-diode PIN attenuator. The structure and operation of the parallel resonant circuit will be described in further detail below.

[0013] In the present specification and in the appended claims, the term "attenuator" is meant to be understood broadly as referring to any circuit in a broadband RF system configured to decrease the sensitivity, measured in decibels, of the system. According to one exemplary embodiment, attenuators may be used in situations where a desired signal is too strong to be effectively processed.

[0014] Moreover, the term "PIN diode" or "positive-intrinsic-negative diode" refers to a diode with a large intrinsic (I) region sandwiched between a P- and an N- doped semiconducting regions. PIN diodes appear as an almost pure resistance at RF. The value of this resistance can be varied over a range of approximately 1 to 10,000 ohms by direct current control.

[0015] Additionally, the term "tilt" refers to a difference in signal amplitude between the highest and lowest system frequencies. Similarly, the term "down tilt" refers to an un-intentional increase in attenuation in a 6-diode PIN attenuator that corresponds with an increase in frequency. A down tilt may be caused by any number of parasitic reactances occurring in the 6-diode PIN attenuator that increase with increased frequency.

[0016] In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present system and method for providing tilt correction to a 6-diode PIN attenuator. It will be apparent, however, to one skilled in the art that the present method may be practiced without these specific details. Reference in the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. The appearance of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

Exemplary Overall Structure

[0017] For a variable attenuator, the series (130) and shunt (140, 150) resistive elements illustrated in the constant impedance attenuator circuit of Figure 1 are replaced with PIN diodes, which can act as variable resistors. Figure 2 illustrates an exemplary variable attenuator (200) incorporating PIN diodes as the series (220) and shunt (250, 255) resistive elements. As shown in Figure 2, a variable attenuator (200) may include both a signal input (205) and a signal output (210). Disposed between the signal input and the signal output is a variable attenuator circuit (200). The variable attenuator circuit (200) includes a series resistive element (220) in the form of a PIN diode coupled in series with a plurality of capacitors (230, 235), one disposed on each end of the series resistive element. A pair of PIN diodes (250, 255) is also coupled in the shunt legs as the shunt resistive elements.

[0018] A shunt bias may be provided to the shunt leg PIN diodes (250, 255) through a resistive element (215) as illustrated in Figure 2. The configuration including the capacitive element (240) illustrated in Figure 2 allows the PIN diodes in the shunt legs (250, 255) to be coupled in series from a DC bias perspective and in parallel from an RF perspective. The shunt bias provided to the PIN diodes in the shunt legs (250, 255) may be varied. As the shunt bias is increased, the current passing through the PIN diodes (250, 255) is increased causing the impedance of the shunt diodes (250, 255) to be reduced. Conversely, if the shunt bias is decreased, the impedance of the shunt diodes (250, 255) is increased. Similarly, a series bias is provided to the PIN diode acting as the series resistive element (220) through a resistive element (225). Variations of the series bias will affect the impedance of the series PIN diode (220) in a similar manner as mentioned above. Additional elements included in the variable attenuator circuit (200) such as the inductor (245) and the capacitors (230, 235) may be included to remove any residual RF energy from the DC bias lines or signals by filtering and bypassing.

[0019] While Figure 2 illustrates one means for applying and controlling the forward bias currents which flow through each PIN diode (250, 255, 220) in the variable attenuator (200), one skilled in the art will recognize that there are additional configurations that may be used to apply and control the forward bias currents. Additional methods for applying and controlling the forward bias currents include, but are in no way limited to, the use of bias chokes, blocking capacitors, networks of resistors, diodes, op-amps, or appropriate

combinations thereof. While various methods for applying and controlling forward bias currents exist, one commonality is that the current in the shunt diodes are equal and the ratio of the shunt and series currents is such that the required impedance is maintained as the attenuation is varied.

[0020] However, as noted above, an increase in the attenuation levels often increases the amount of down-tilt experienced by the variable attenuator (200). In general, such attenuator circuits do not maintain a flat or frequency independent response as the attenuation is increased. This is due to inherent parasitic reactances associated with the diode (220, 250, 255) components. This increase in down-tilt makes it difficult to maintain tight tilt specifications during operation.

[0021] Figure 3 illustrates an exemplary circuit (300) that functions as an electronically variable RF attenuator (300) with a large attenuation range while maintaining a flat frequency response throughout its attenuation range. As shown in Figure 3, the exemplary circuit includes a pair of shunt diode circuits (350, 370) and a pair of series diodes (330, 332). Each shunt diode circuit (350, 370) includes a pair of PIN diodes (352, 356, 372, 376) coupled in series. Additionally, each shunt diode circuit (350, 370) includes a capacitive element (354, 374) as illustrated in Figure 3. The capacitive elements (354, 374) allow the diodes (352, 356, 372, 376) in the shunt circuits to be connected in parallel, from an RF perspective, while being in series from a DC bias perspective. The series diode (330) and series diode (332) together, provide the series leg of the RF attenuator (300) illustrated in Figure 3.

[0022] Also similar to the exemplary circuit illustrated in Figure 2, the RF attenuator circuit (300) illustrated in Figure 3 includes an RF input (318) and an RF output (344) coupled to the circuit elements. Disposed between the RF input (318) and the initial components of the shunt diode circuits are a number of components (320, 322, 324, 326, 328) that condition the received RF signal prior to attenuation. Additionally, a number of components (334, 336, 338, 340, 342) condition the RF signal after attenuation prior to the RF output (344).

[0023] A series bias input (302) is also illustrated in Figure 3 electrically coupled to a node disposed between the pair of series diodes (330, 332). A controlled voltage at the series bias input (302) produces the bias current that determines the impedance of the series

diodes (330, 332). The current path from the series bias input (302) to the series diodes (330, 332) is through a plurality of resistive elements (304, 310) and an inductive element (316) to reach the series diodes (330, 332). A plurality of capacitive elements (306, 308, 312, 314) coupled to ground (398) as illustrated in Figure 3 are also coupled to the series bias input (302) to serve as decoupling components used to remove any residual RF energy from the DC bias lines by filtering and bypassing. A DC bias voltage applied to the series bias input (302) produces a current that flows through resistive elements (304, 310) then splits equally between the series diode (330) and resistive element (326) on one hand, and the series diode (332) and resistive element (338) on the other. According to one exemplary embodiment, each diode (330, 332) in the series combination is biased with an equal current whose value is determined by the voltage at the series bias input (302). As the series bias current is increased, the impedance of the series diodes is reduced.

[0024] Similar to the series bias input (302), a shunt bias input (394) is also disposed on the RF attenuator circuit (300). The shunt bias input (394) is configured to receive a DC bias voltage applied at shunt bias input (394) that produces a DC current through the resistive elements (368, 392) connected in series. That current then follows a path through resistive element (346), shunt diode (356), shunt diode (352), and resistive element (326) to ground (398). Simultaneously, an equal current flows through resistive element (379), shunt diodes (372, 376), and resistive element (338) to ground (398). Varying the bias voltage applied at the shunt bias input (394) varies the current through the diodes (350, 356, 372, 376) and, therefore, controllably varies their impedance. The remaining components coupled to the shunt bias input (394) such as capacitive element (388), inductive element (390), capacitive element (389), capacitive element (348), and capacitive element (396) are decoupling components used to remove any residual RF energy from the DC bias lines by filtering and bypassing.

[0025] In general, if the ratio of the impedance of the above-mentioned elements is correct, constant impedance (75 ohms according to one exemplary embodiment) can be provided, independent of the attenuation value. By controlling the bias current through the diodes, any attenuation value, over a range of 15 dB or more, is possible, with constant impedance. However, as noted above, the ratio of the impedance of the above-mentioned elements is not always correct at all frequencies due to any number of parasitic reactances

occurring in the 6-diode PIN attenuator (300) that increase with increased frequency, resulting in down tilt.

[0026] According to one exemplary embodiment, a parallel resonant circuit (360, 380) is coupled to the shunt diode circuits (350, 370) as illustrated in Figure 3 to cancel the effect of parasitic reactances elsewhere in the attenuator circuit (300). According to one exemplary embodiment shown in Figure 3, each parallel resonant circuit (360, 380) includes a plurality of capacitive components (358, 364, 378, 384), an inductive component (362, 382), and a resistive component (366, 386) coupled to the shunt diode circuits (350, 370) and ground (398) as shown in Figure 3. These parallel resonant circuits (360, 380) including the inductive components (362, 382) and the capacitive components (364, 384) coupled in parallel have a wide resonance bandwidth and are resonant at a frequency that is slightly higher than the highest signal frequency. As a result, these circuits exhibit high impedance at the highest signal frequencies and progressively lower impedance as frequency decreases. The parallel resistive elements (366, 386) are included to limit the maximum impedance. From an RF signal point of view, the parallel resonant circuits (360, 380) are coupled in series with the shunt legs of the attenuator.

Exemplary Implementation and Operation

[0027] During operation of the RF attenuator circuit (300) illustrated in Figure 3, a controlled bias current at the series bias input (302) is provided to produce the bias current that determines the impedance of the series diodes (330, 332) through the current path illustrated above. Additionally, a controlled bias current is provided to the shunt bias input (394) to control the impedance of the shunt diodes (352, 356,372, 376) through the current path illustrated above.

[0028] One of ordinary skill in the art will note that the diode pairs (352, 356, 372, 376) are coupled in series for the DC bias (incurring equal currents in both), but in parallel for RF signals received by the circuit. This configuration produces a minimum impedance that is approximately 50% of that of a single diode, and makes very large attenuation ranges possible. By applying appropriate voltage values at the shunt bias input (394) and the series bias input (302), the attenuator circuit can be caused to produce any specific attenuation value while maintaining the correct impedance match. A low attenuation value results from a high

bias current through the series diodes (330, 332) and a low bias current through the shunt diodes (352, 356, 372, 376). Conversely, a high attenuation value results when the series diode bias current is low and the shunt diode bias current is high. In practice, the bias voltages required for any given attenuation value are determined experimentally and stored in a digital lookup table (not shown). A microprocessor-based embedded intelligence section (not shown) of the apparatus incorporating the present RF attenuator circuit (300) may then look up a number of bias values and regenerates them via digital-to-analog conversion.

[0029] As the impedance of the shunt diodes (352, 356, 372, 376) becomes lower, the effect of the parallel resonant circuits (360, 380) increases, just as the undesirable tilt increases. As the impedance of the shunt diodes (352, 356, 372, 376) decreases the resonant circuits (360, 380), consequently, represent an increasing percentage of the total shunt impedance. Since the resonant impedance increases with frequency, the attenuation decreases with frequency, the magnitude of the effect being proportional to actual attenuation. This effect tends to cancel the effect of parasitic reactances elsewhere in the RF attenuator circuit (300), which tends to increase attenuation with frequency, producing an attenuation that does not vary with frequency, regardless of attenuation setting. By incorporating proper component values in the parallel resonant circuits (360, 380), the "tilt" effect will be accurately compensated and a "flat" loss versus frequency response will result at all loss settings.

[0030] According to one exemplary embodiment illustrated in Figure 4, the present RF attenuator circuit (300; Fig. 3) forms a part of an optical transmitter product such as a laser transmitter. As shown in Figure 4, the laser transmitter module (400) has a basic function of accepting a broadband RF input signal and optically modulating the output of a laser (440) using the input signal. The laser's output is then coupled into an optical fiber (not shown) for transmission to a remote location. Within the laser transmitter module (400), the RF signal is first buffered, or amplified (410), then applied to the present attenuator circuit (420). Once the signal is attenuated by the present attenuator circuit (420), the attenuated RF signal is again amplified by an amplifier (430) and is then applied to an input of a laser (440). The RF signal level at the laser (440) is measured by an RF power meter (450) or other metering device and compared to a predetermined value stored in a digital control (460) having imbedded intelligence/firmware. Upon comparison, the digital control (460) produces

an error value that is then used to adjust the loss of the attenuator circuit (420) such that the RF level at the laser (440) input is maintained at an optimum value. Consequently, the overall effect is that despite large variations in the module's RF input level and fluctuations of gain or loss elsewhere in the RF signal path with time or temperature the laser RF input level remains optimized.

[0031] The bias voltages are provided to the attenuator circuit (420) by a firmware based digital control system (460). This embedded logic system measures the RF level of the signal applied to the laser (440) and uses the attenuator (420) to maintain precise control of the laser's operating point, despite variations in the product's input signal level or internal gain. The incorporation of the present parallel resonant circuits (360, 380; Fig. 3) increases the precision with which the laser's operating point may be controlled because the attenuator (420) is no longer plagued by unwanted tilt effects.

[0032] While the above exemplary embodiment illustrates one possible 6-diode PIN attenuator configuration incorporating a tilt correction circuit, the present system and method are in no way limited to the exemplary configuration illustrated herein. Rather, the present system and method may be incorporated into any number of attenuator configurations including any number of component combinations by coupling the exemplary parallel resonant circuits (360, 380) to the shunt diodes to eliminate the effect of parasitic reactances elsewhere in the attenuator circuit.

[0033] In conclusion, the present system and method illustrate a 6-diode PIN attenuator with tilt correction. More specifically, the present system includes the coupling of a parallel resonant circuit to each shunt leg of an attenuator. By coupling the parallel resonant circuit to the shunt legs of the 6-diode PIN attenuator, the undesirable tilt may be effectively reduced. As the impedance of the shunt diodes of the 6-diode PIN attenuator decrease, the resonant circuits will represent an increasing percentage of the total shunt impedance. Since the resonant impedance increases with frequency, the attenuation decreases with frequency, with the magnitude of the effect being proportional to actual attenuation. This effect tends to cancel the effect of parasitic reactances elsewhere in the RF attenuator circuit, which tends to increase attenuation with frequency, producing an attenuation that does not vary with frequency, regardless of attenuation settings. This reduction in attenuation variation due to

changes in frequency allows the maintenance of tight tilt specifications in equipment incorporating the present attenuator.

[0034] The preceding description has been presented only to illustrate and describe the present method and system. It is not intended to be exhaustive or to limit the present system and method to any precise form disclosed. Many modifications and variations are possible in light of the above teaching.

[0035] The foregoing embodiments were chosen and described in order to illustrate principles of the system and method as well as some practical applications. The preceding description enables others skilled in the art to utilize the system and method in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the system and method be defined by the following claims.